Improving Reliability of Long Pulsewidth High Power Laser Diode Pump Arrays

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Laser Diode Pump Arrays

Significance of LDAs to NASA

- Solid state and fiber lasers play a major role in meeting NASA's immediate and future objectives
- Pump LDAs are the most critical component of lasers defining their efficiency, lifetime and reliability
- Results of LaRC's work, emphasizing more challenging 792nm LDA, directly applies to all high power LDAs

Relevance To Earth Science

- 2-micron Lidars for global measurements of winds and CO2
- 1-micron and 1.5-micron Lidars for altimetry, ozone, CO2, winds, aerosol measurements

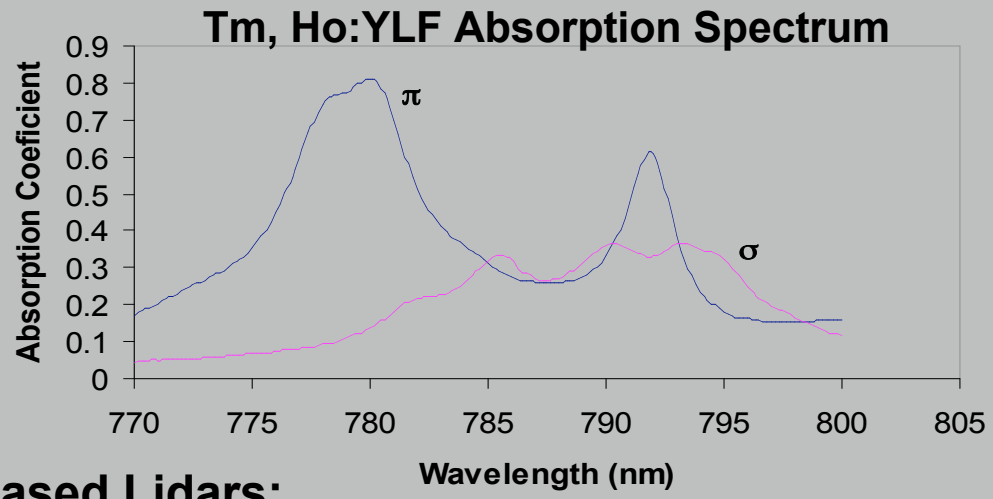
Relevance to Space Exploration

- planetary mapping
- hazard avoidance
- pinpoint landing guidance
- rendezvous and docking
- high data rate optical communication links
- laser remote sensing of atmospheric parameters such as winds, density, temperature, and aerosol concentration

Laser Diode Pump Arrays

BACKGROUND

- Moderate and High pulse energy solid state lasers require High Power Quasi-CW 2-D Pump Arrays
  - 2-micron lasers - 792 nm and 1000 μsec pulse duration
  - 1-micron lasers - 808 nm and 200 μsec pulse duration



General Requirements for Space-based Lidars:

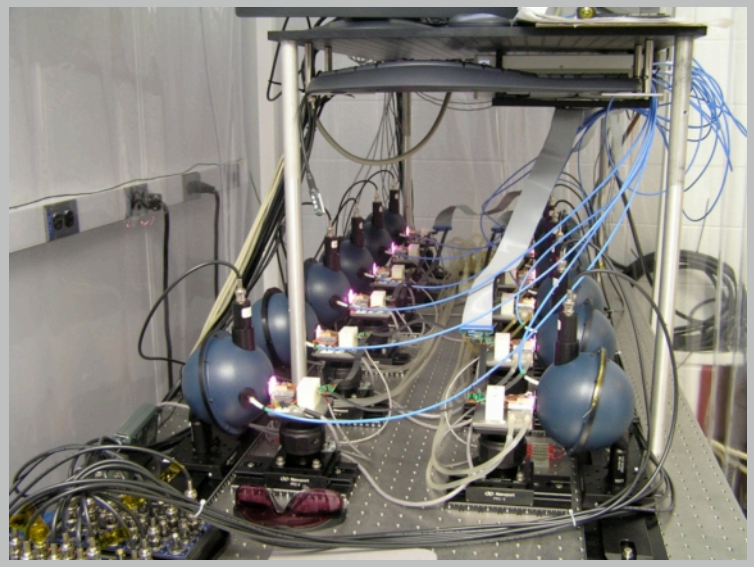
- Conductively-cooled
- Long lifetime > 2 x 10^9 shots
- Reliability better than 300 FIT/6-bar device and 1000 FIT/bar
- Spectral width < 3 nm

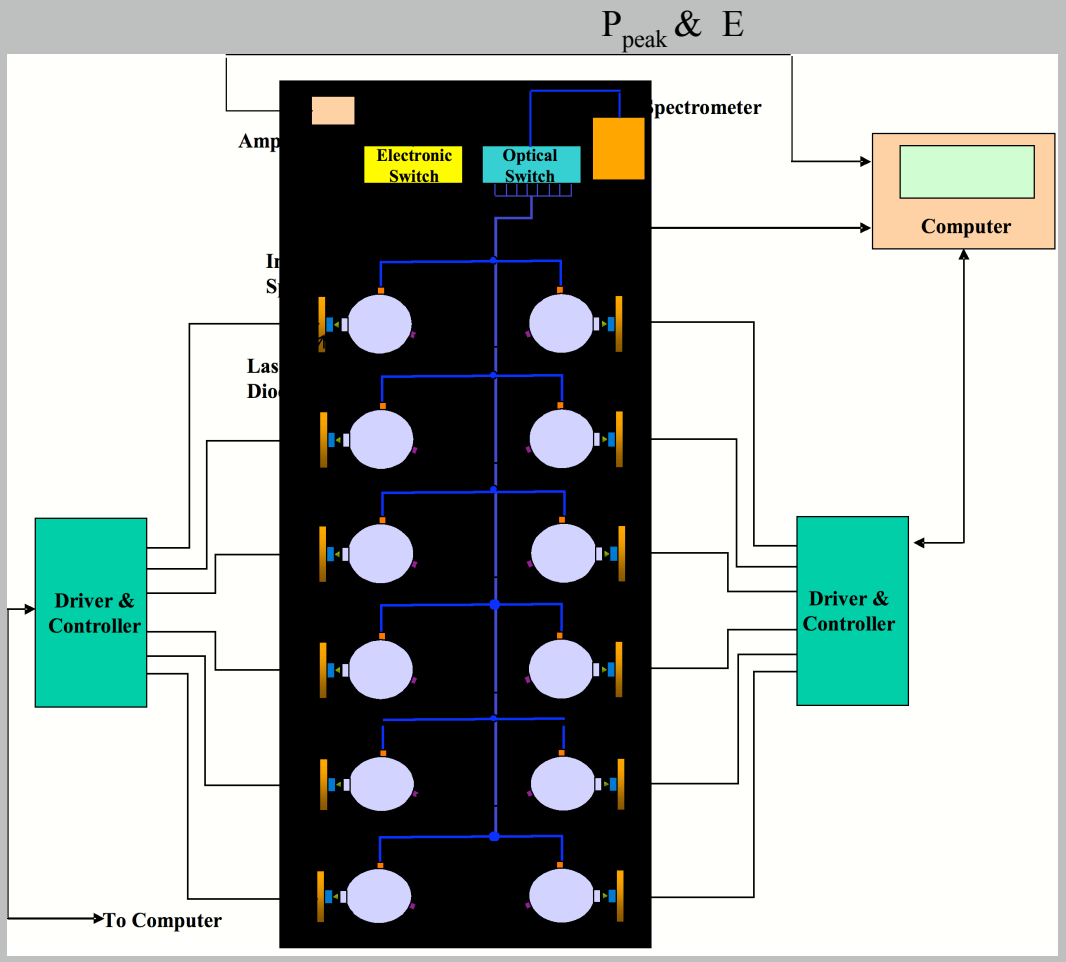
Lifetime Testing of 792 nm LDAs

- LDAs are being tested at full rated power and expected operational parameters for a space-based 2-micron lidar system
  - Drive current 100 A
  - Rep. rate 12 Hz
  - Pulse duration 1 msec
  - Operating temp. 25 deg. C
- Began lifetime testing of Standard "A" and "G" packages in February 2004
- LDAs from 2 suppliers representing a sample of over 100 6-bar arrays characterized at Langley

Laser Diode Characterization/Lifetime Test Facility

Lifetime Test Facility



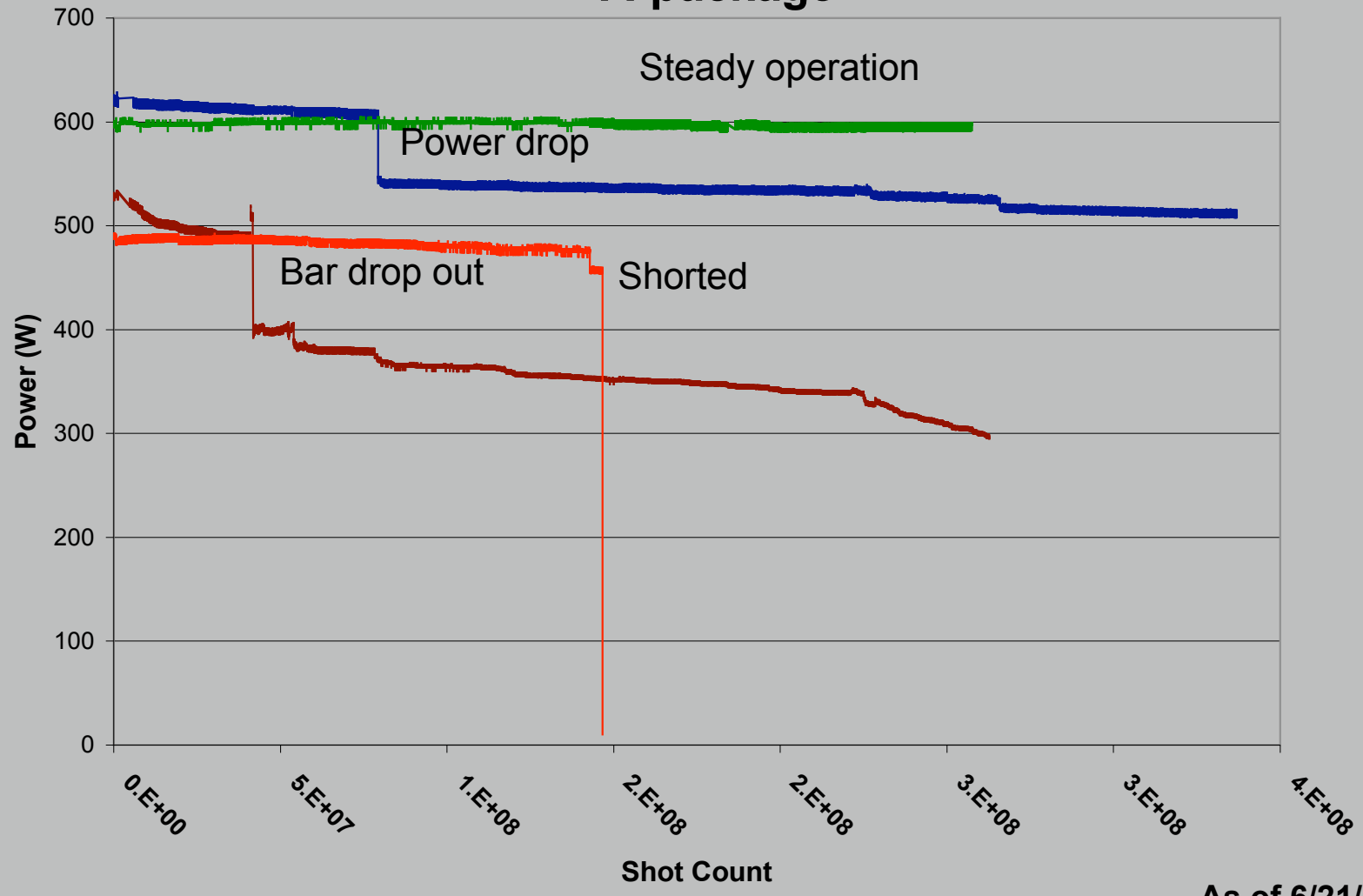


- Measures 12 LD Arrays Simultaneously - 24/7 operation. (Modularly expandable).
- Fully Automated
  - Control and Operation
  - Data Acquisition and Archive (Performance and all relevant environmental parameters)
  - Diagnosis and Alert
  - PC/Web-based

Lifetime Testing of 792 nm LDAs

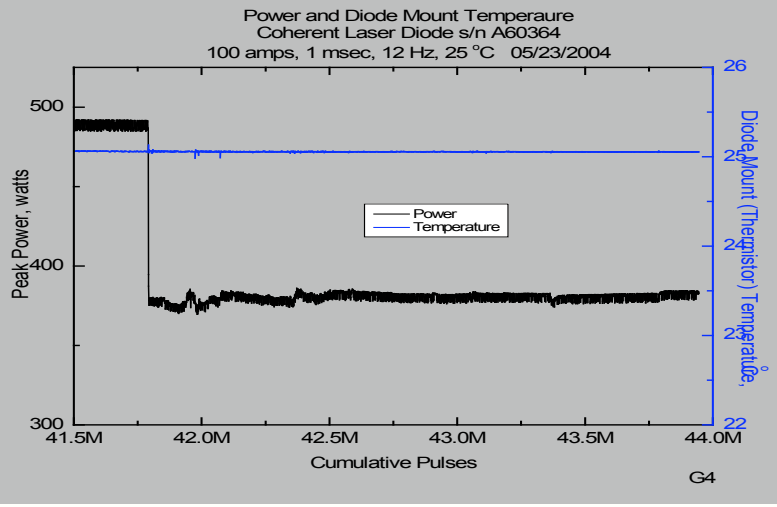
Supplier A

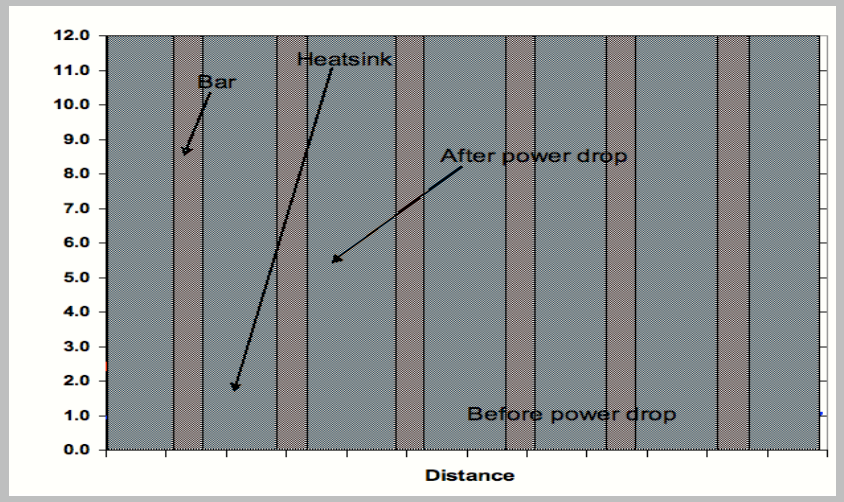
A-package



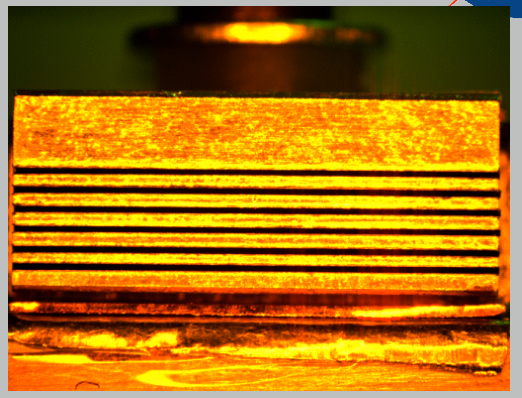
As of 6/21/2005

Lifetime Testing

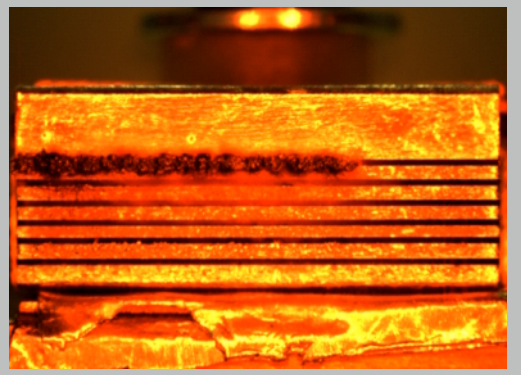


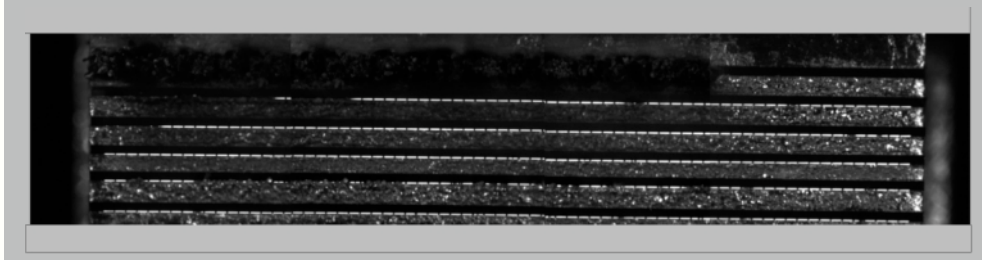


Before



After Bar Drop Out

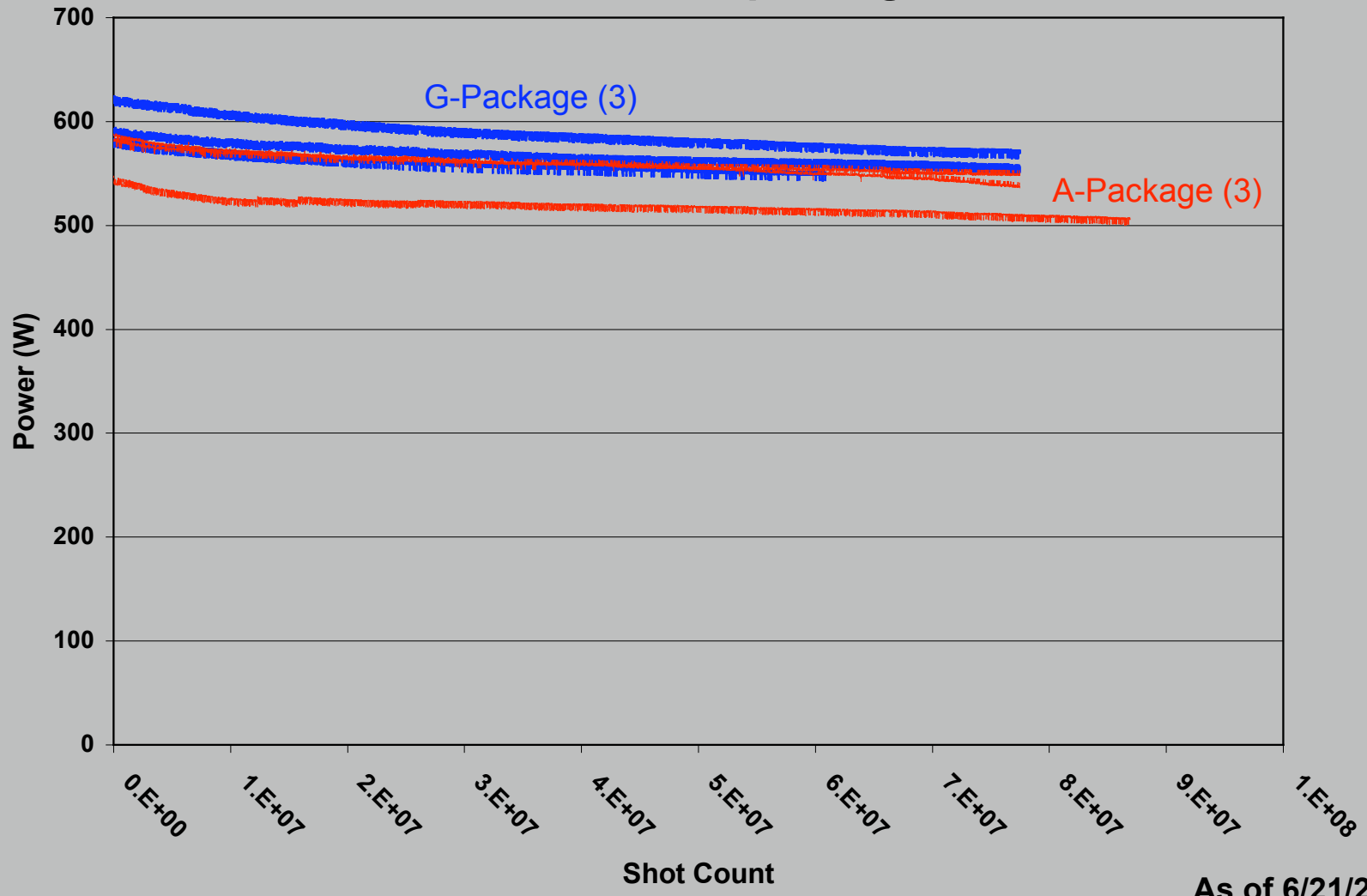




Lifetime Testing of 792 nm LDAs

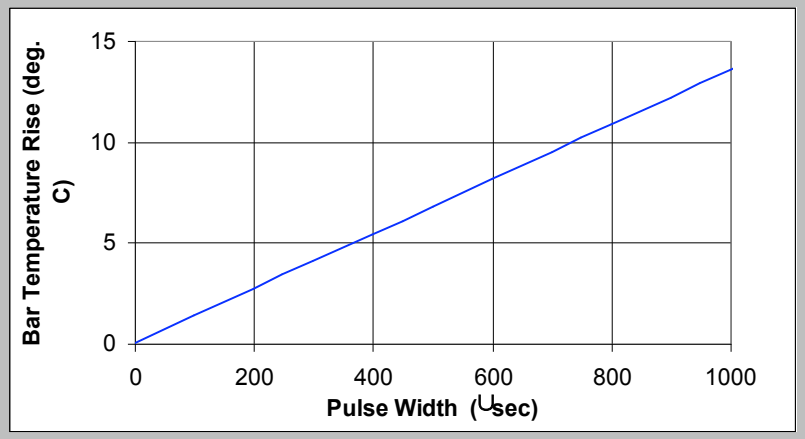
Supplier B

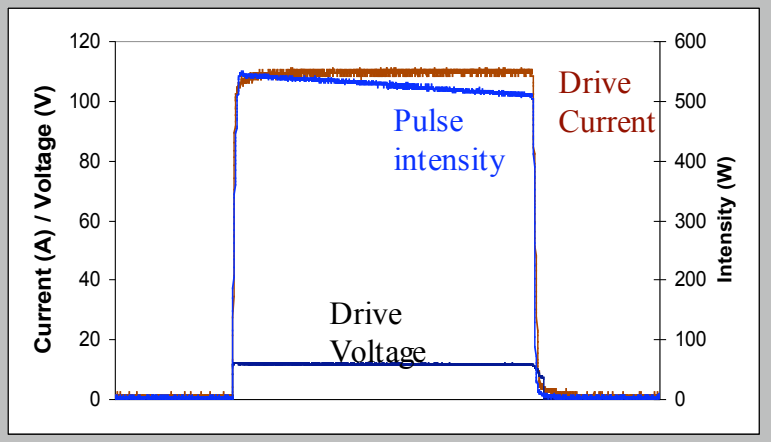
A and G package

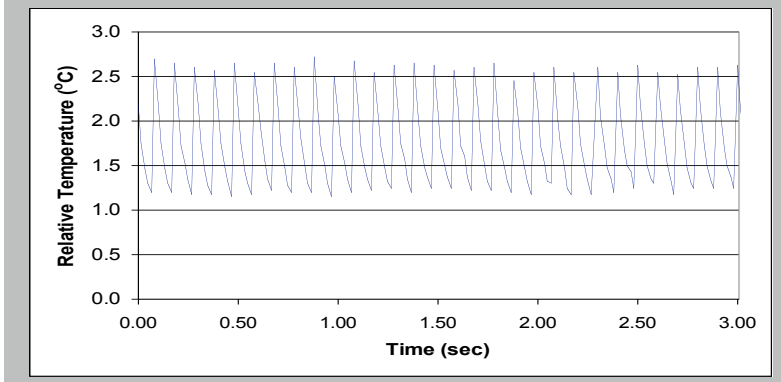


As of 6/21/2005

Thermal Cycling of Quasi-CW Laser Diode Array

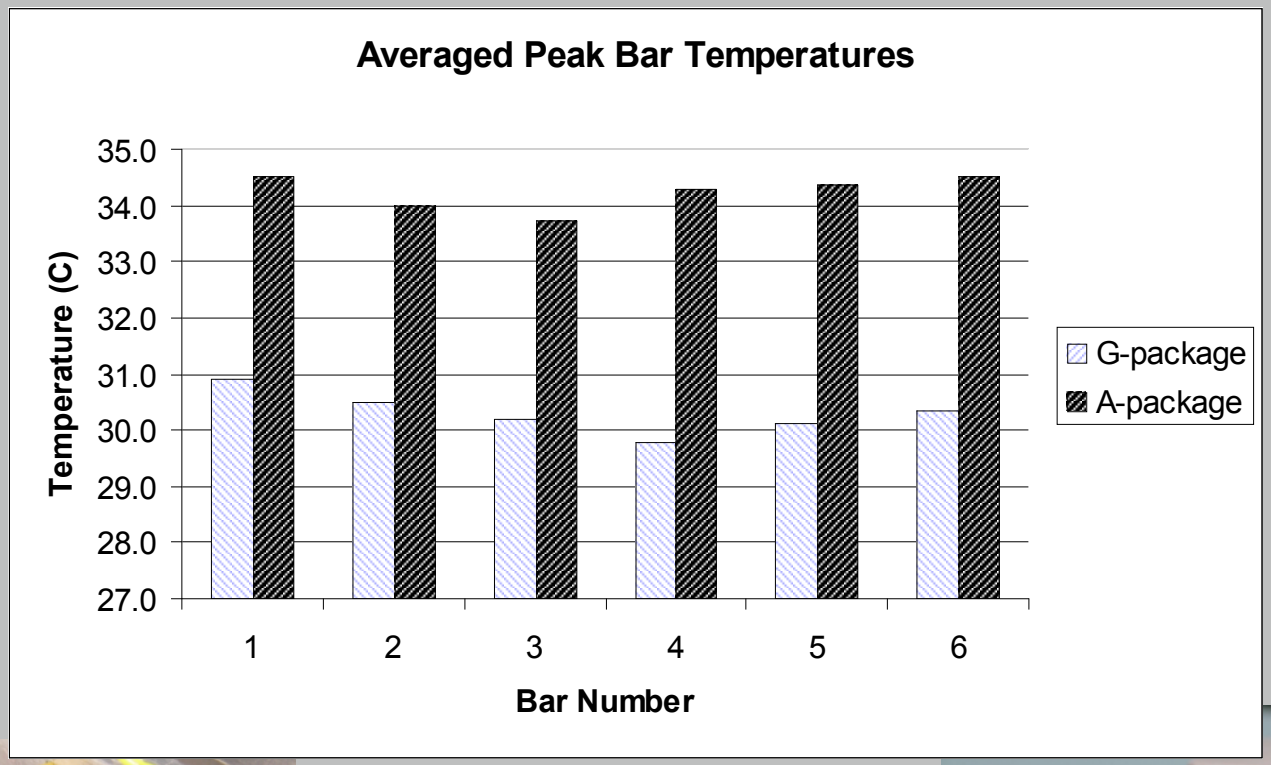


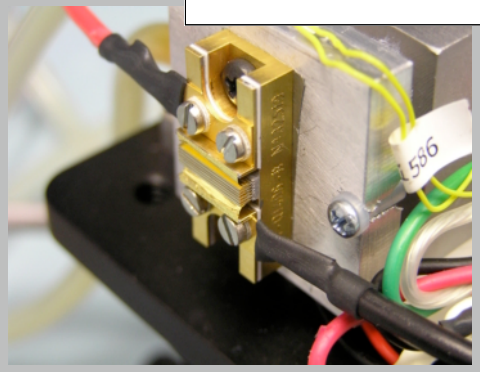




Comparison of Different LDAs

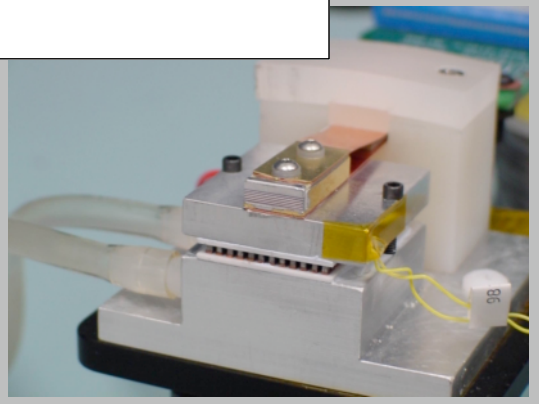
G-package bars run about 4 degrees cooler than A-package





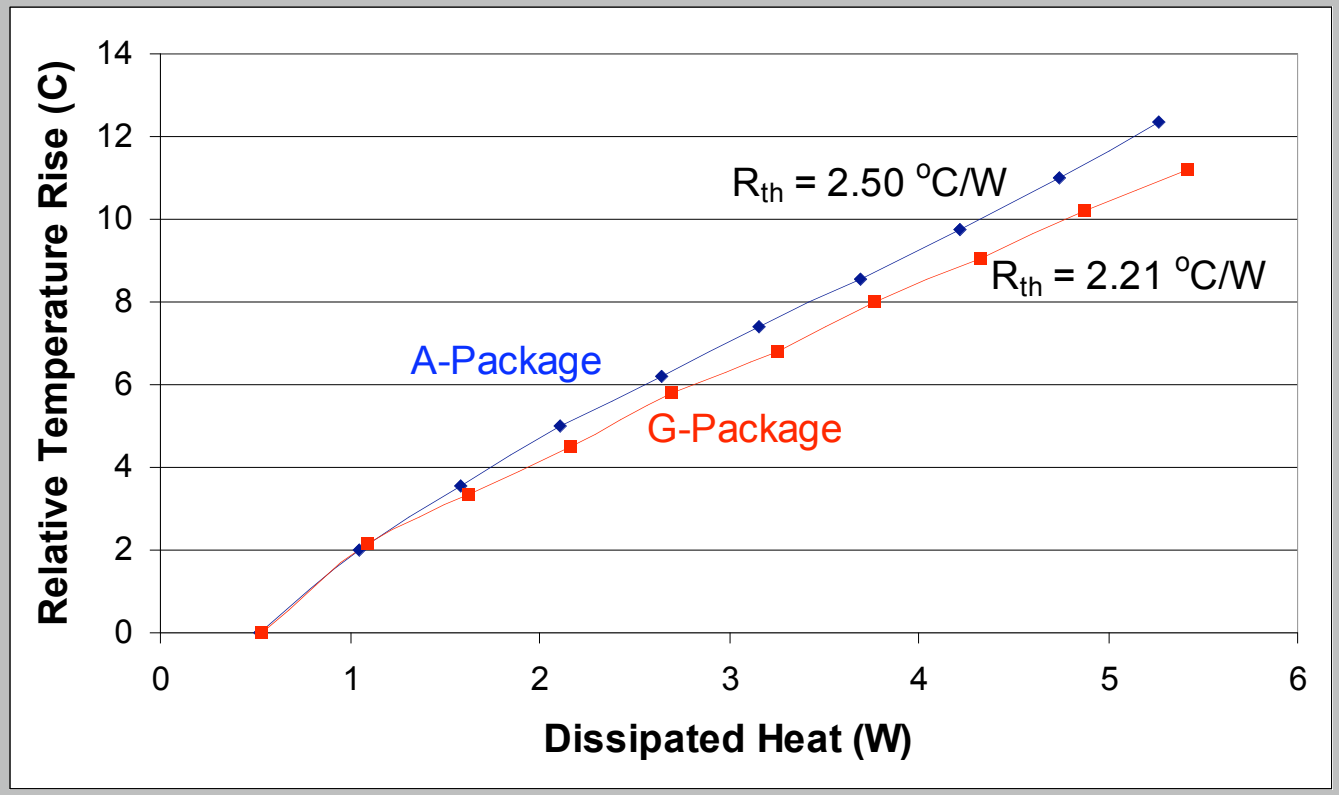
G-package

A-package



Comparison of Different LDAs

Thermal resistance of G-package is about 13% lower than A-package



Improving Lifetime and Reliability of Long Pulse Duration LDAs

Using existing LDAs and current state of technology

Plan and Recommendations	Lifetime	Reliability
Use G-package instead of A-package	X	X
Use 500μm pitch instead of 400μm		X
Operate at a de-rated level (> 25%)	X	
Proven consistent fab/assembly processes		X
Proper screening and testing procedures		X

Improving Lifetime and Reliability of Long Pulse Duration LDAs

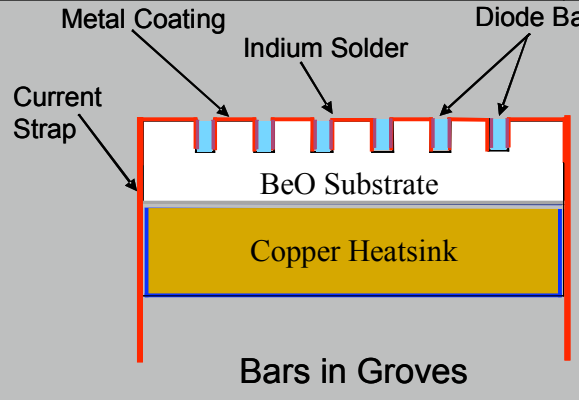
Advancing Technology

Promising Technologies Under Development	Lifetime	Reliability
Advanced package materials (Composites, CVD Diamond)	X	
Thin hard solder	X	X
Smart Driver	X	
Integrated fuse		X
Efficiency	X	

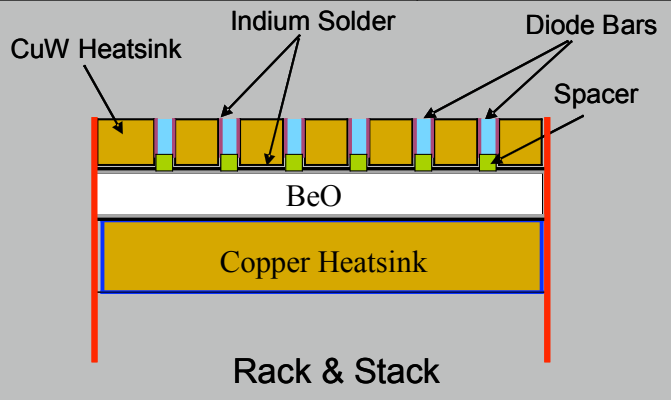
Technology Advancement Addressing Reliability Issues

Thermal properties of package materials

	Material	Coefficient of Thermal Expansion (m/m°C)	Thermal Conductivity (W/m·K)
Standard	GaAs (wafer material)	6.8×10^{-6}	46-55
	Indium Solder	29×10^{-6}	86
	BeO	8×10^{-6}	260
	Copper/CuW	$6 - 8 \times 10^{-6}$	200-250
Advanced	Diamond	1×10^{-6}	1100-1600
	Carbon-Carbon Composites	$1\text{-}6 \times 10^{-6}$	300-600
	Metal Matrix Composites	$6\text{-}16 \times 10^{-6}$	820-890
	AuSn Solder	16	58



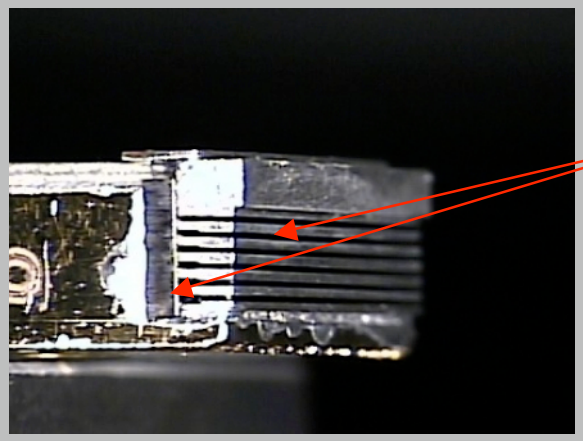
Bars in Groves

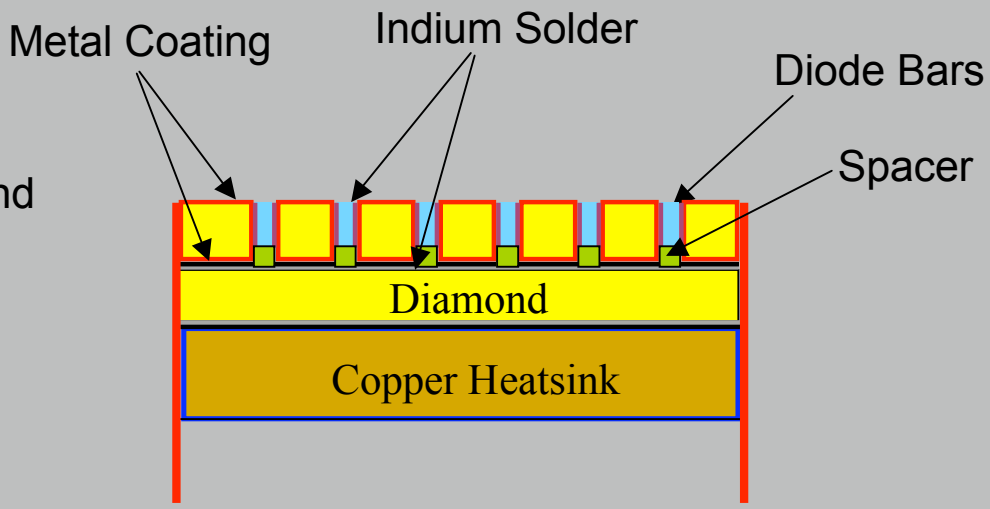


Rack & Stack

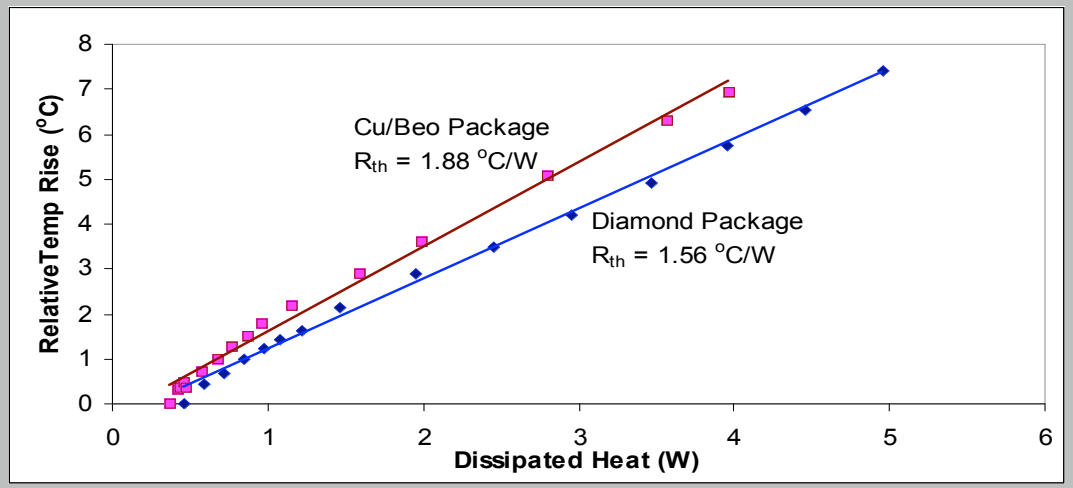
Diamond Laser Diode Array

- *2 different experimental Diamond packages developed earlier showing substantial improvement in heat removal efficiency (*Joint effort with Northrop Grumman/CEO)





Thermal resistance of diamond package is 17% lower than BeO/Cu package

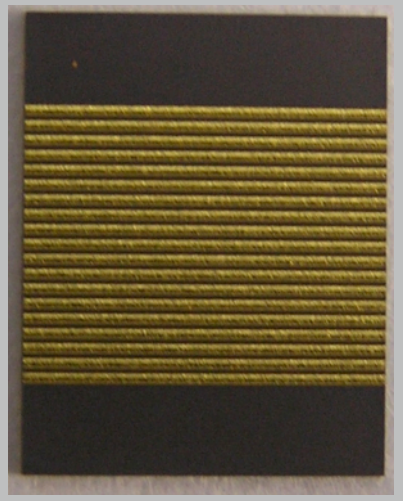


Diamond Laser Diode Array Second Generation

Work on fabrication of a new set of Diamond packages is underway.

- A new set of Diamond submount parts, with even higher thermal conductivity, have been fabricated and delivered
- Single bar packages will soon be fabricated using 808 nm bars to investigate different soldering techniques and performing comparative analysis
- Several 6-bar packages using 792 nm bars from the same lot will be fabricated and tested

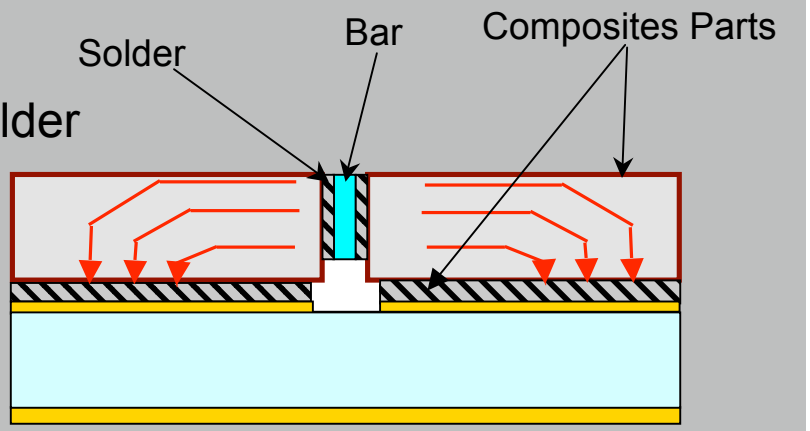
Diamond heatsink parts



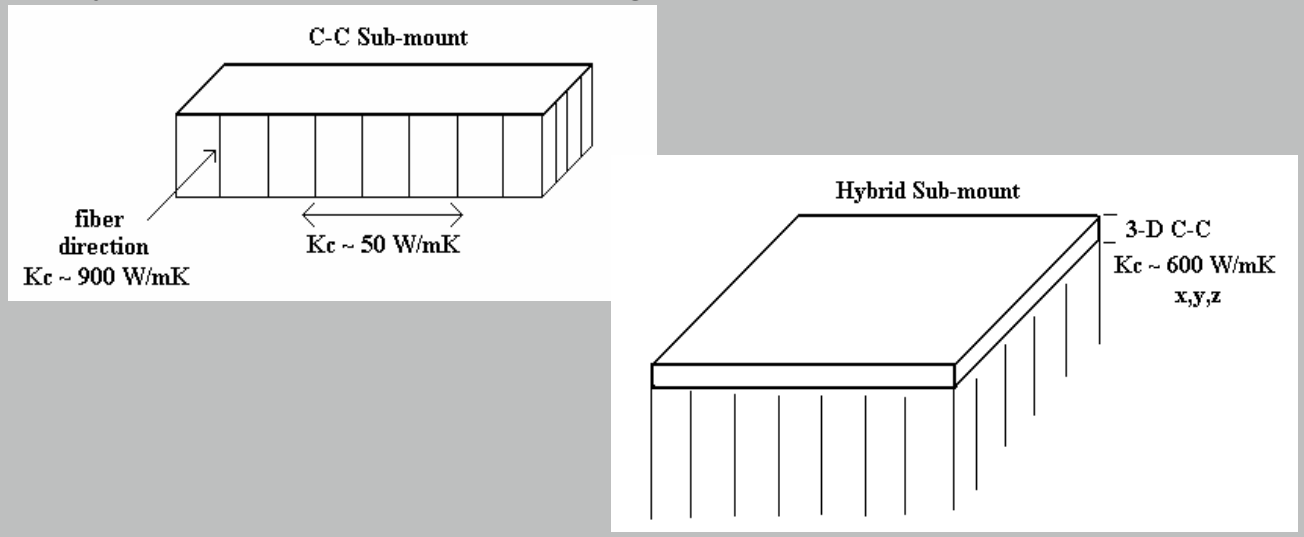
Carbon Composites and Metal Matrix Composites
Laser Diode Arrays

Carbon-Carbon and Metal Matrix Composites provide high thermal conductivity and matching CTE

- Reduce thermal resistance - Longer Lifetime
- Reduce solder thickness or allow use of hard solder - Lower Catastrophic Failure
- Dissipate heat from bars uniformly - Narrower Linewidth

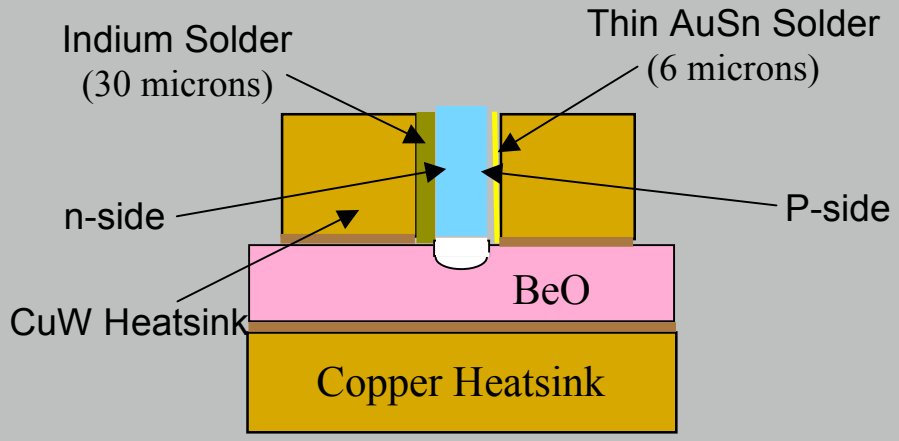


Hybrid C-C Composites / 3-D graphite foam LDA Submount

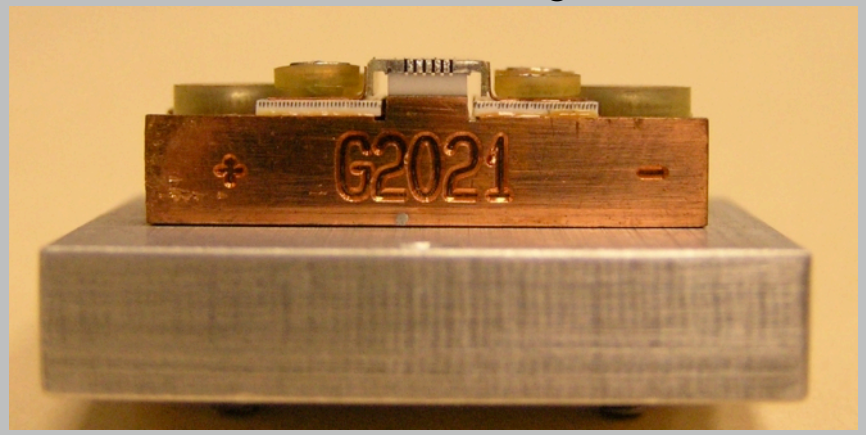


Modified G-Package Laser Diode Array

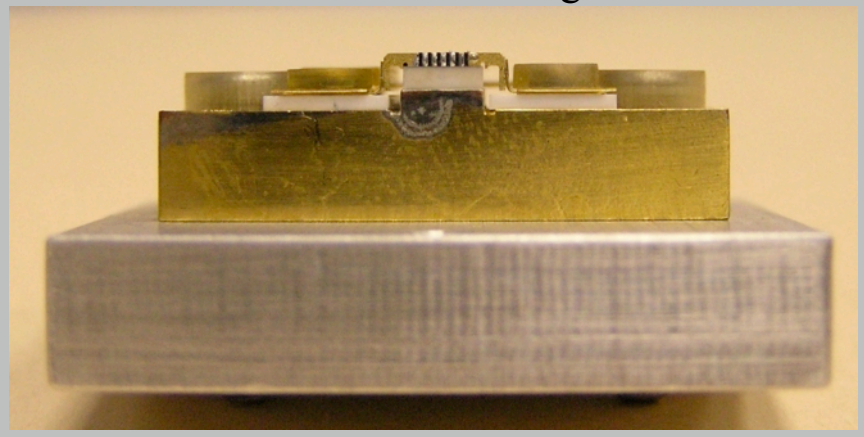
- Fabricated 3 experimental modified 6-bar G-package array and 2 standard packages for comparative measurements
- Thin AuSn hard solder on p-side of the bars and Indium solder on n-side



Standard G-Package



Modified G-Package



Improving Reliability of Long Pulsewidth High Power Laser Diode Pump Arrays

Near Term Plan

- Continue lifetime testing of standard A and G packages from different vendors
- Develop a new setup for measuring thermal-induced mechanical stresses
- Expand lifetime test capability from 12 to 16 stations
- Continue experimenting with thin hard solder
- Complete fabrication of single-bar and 6-bar LDAs using advanced heatsink materials
  - CVD Diamond
  - Hybrid C-C Composites
  - Metal Matrix Composites


NASA LANGLEY RESEARCH CENTER
LASER RISK REDUCTION PROGRAM
LRRP


NASA

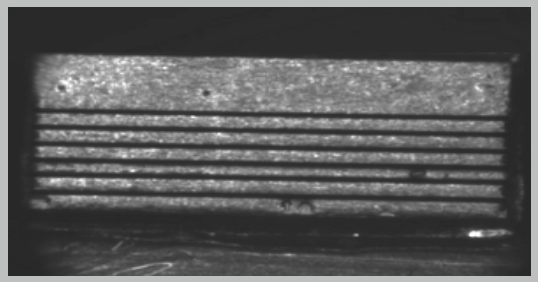
BACKUP

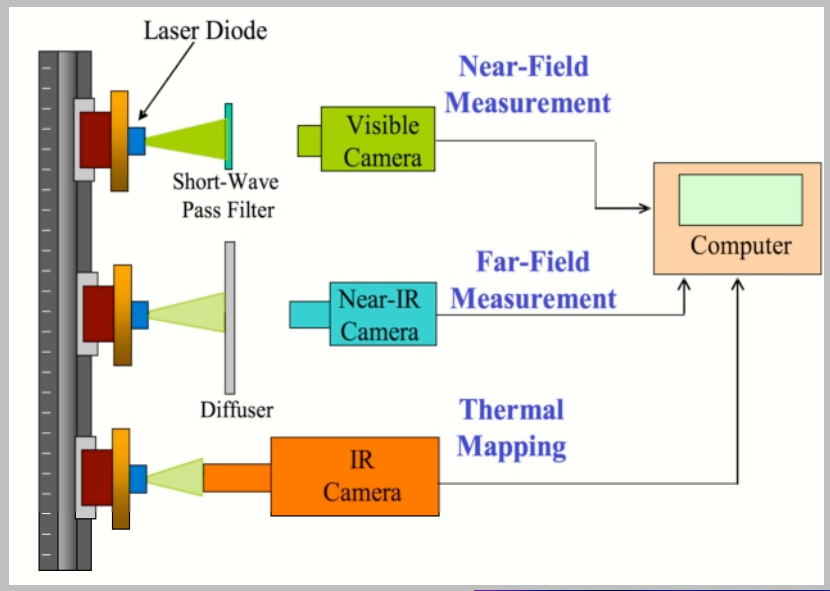
Causes of Laser Diode Failure

Failure Cause	Effect	Comment
Laser Bar Material Defect	Bar Shunt	Wafer growth has improved substantially
Thermal Cycling	Accelerated Aging	Major issue for 2-micron Laser Diode Pump
Solder Creep/Migration	Short Circuit	Soft Indium solder is commonly used
Solder De-bonding	Premature Failure	Production practices and workmanship
Bond Wire Failure	Open Circuit	Used in old SDL diodes (MOLA, GLAS, CALIPSO)

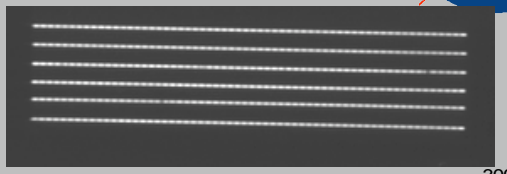
Laser Diode Characterization/Lifetime Testing

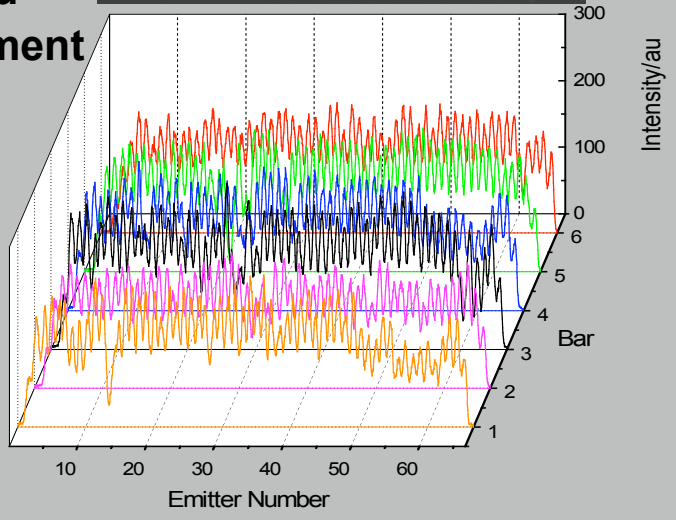
Visual Inspection



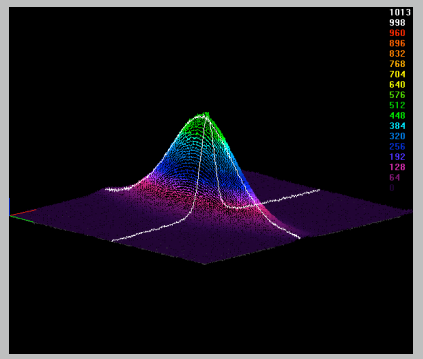


Near-Field Measurement

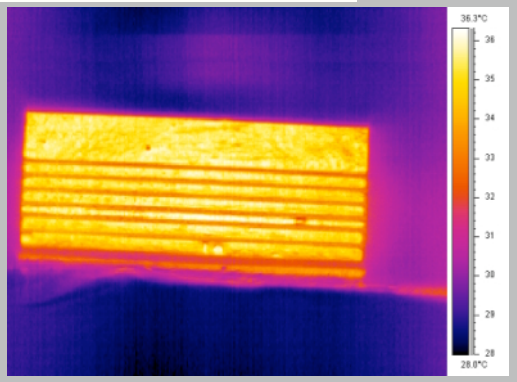




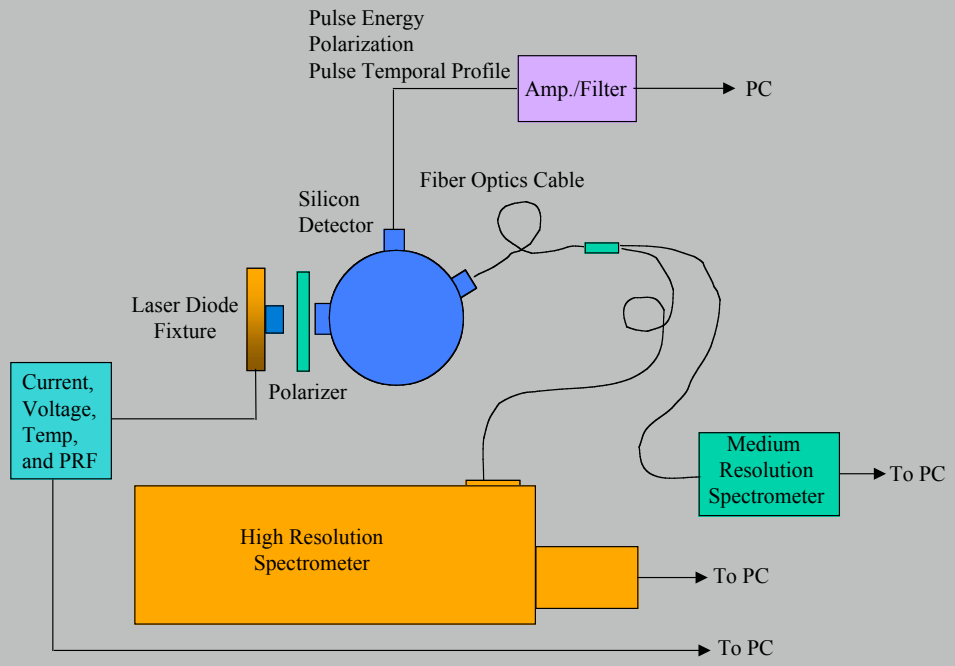
Far-Field Measurement



IR Thermal Imaging



Laser Diode Characterization/Lifetime Testing

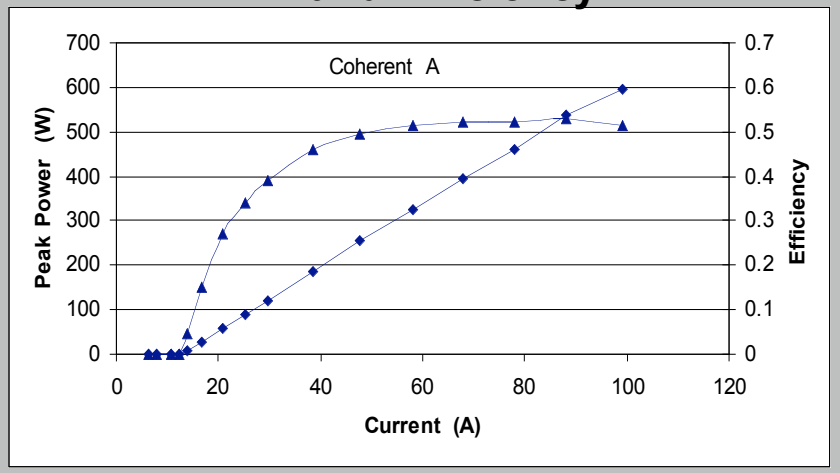


Pulsewidth 1 msec

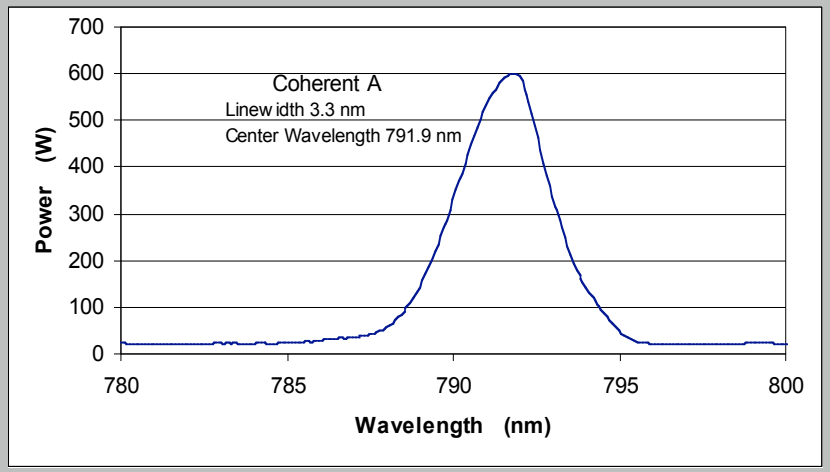
Rep Rate 12 Hz

Op Temp 25 °C

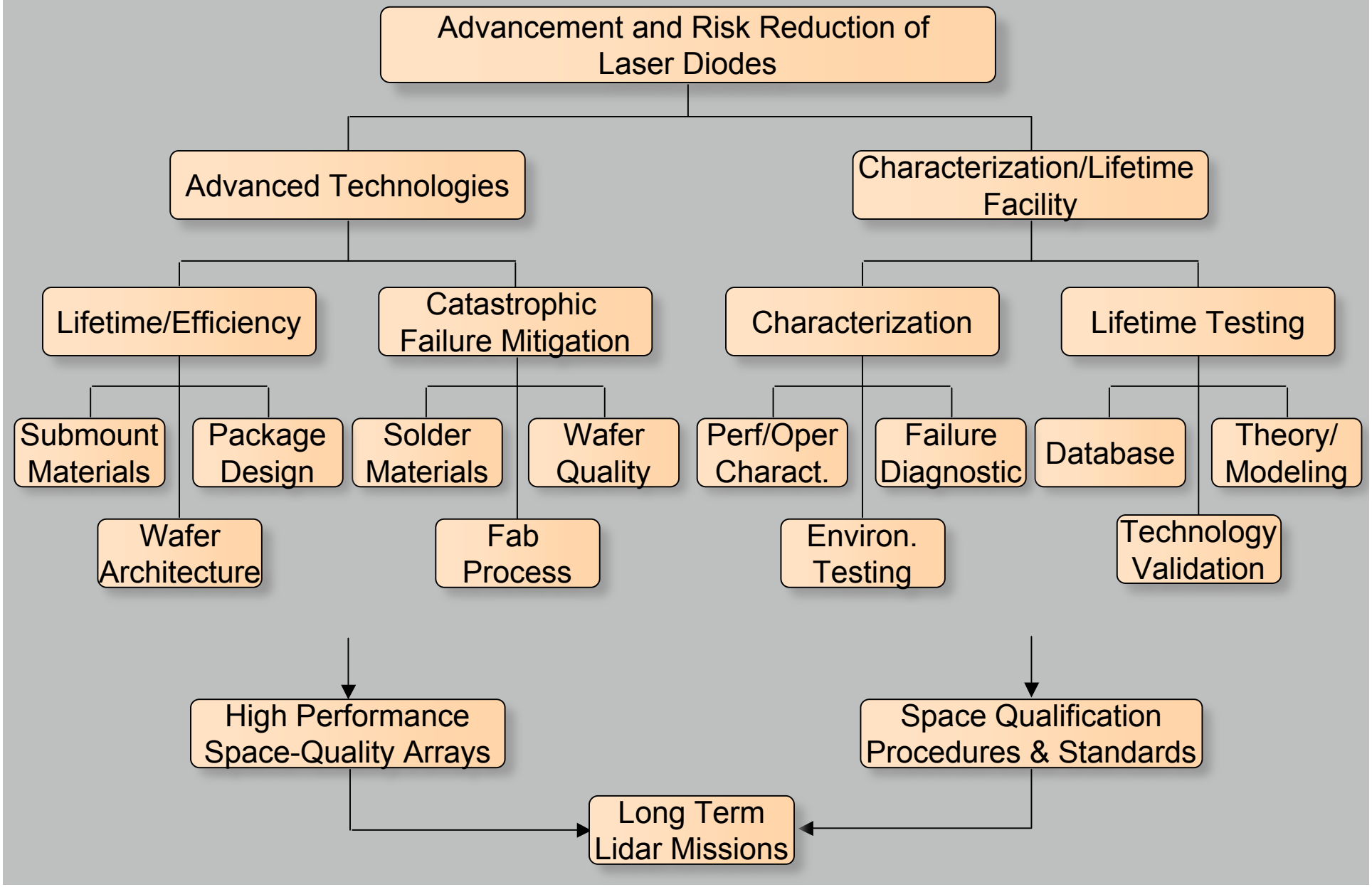
P-I and Efficiency



Spectrum

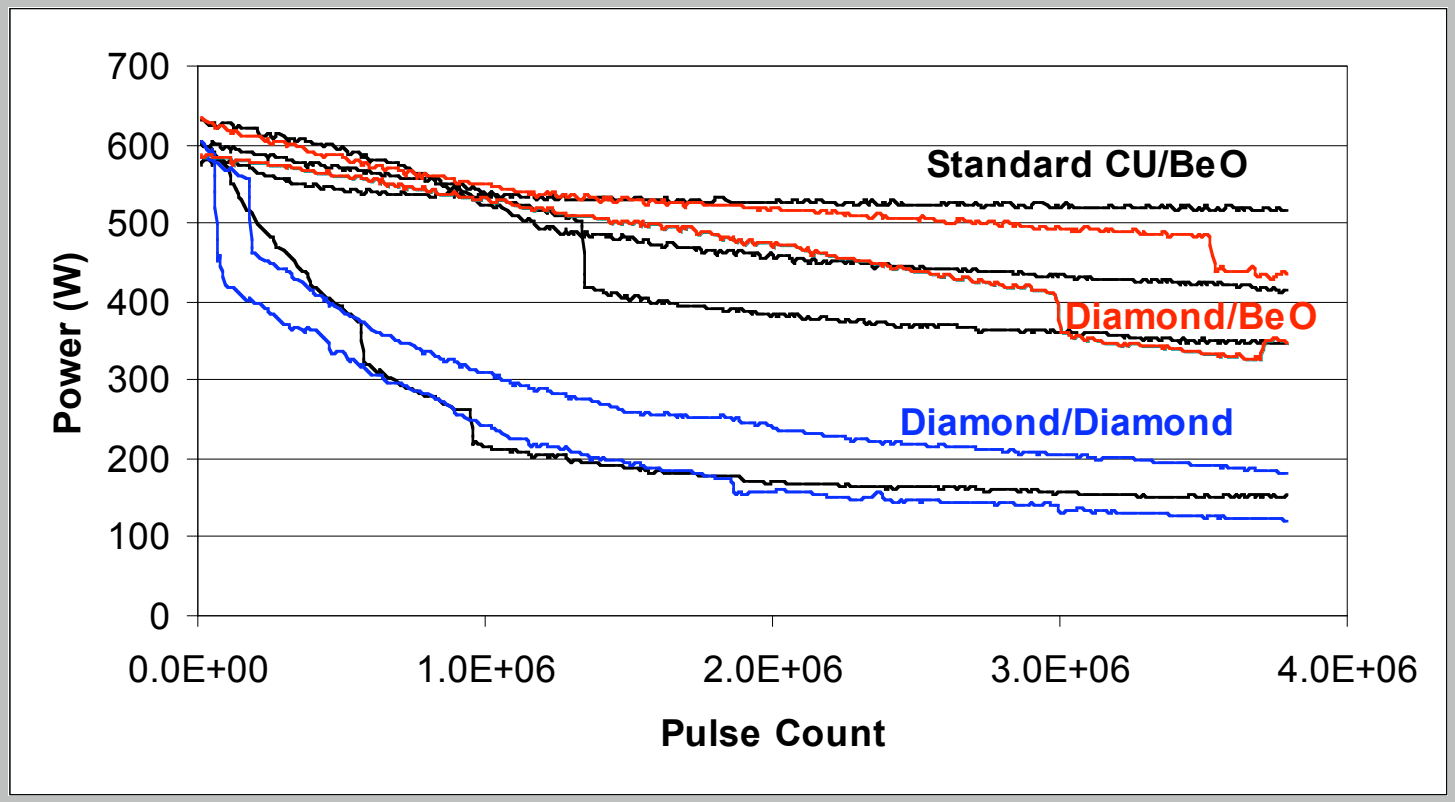


High Power Laser Diode Array Pump
NASA/LaRC Current and Planned Activities



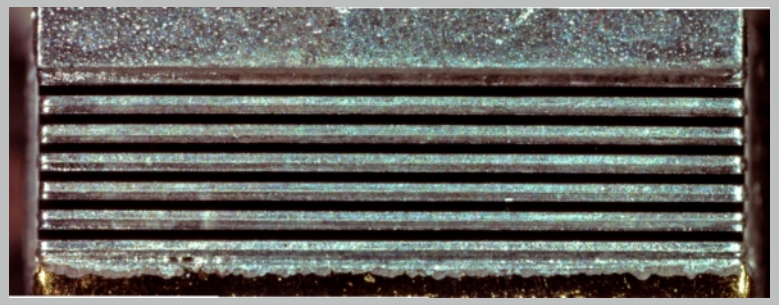
Diamond Laser Diode Array

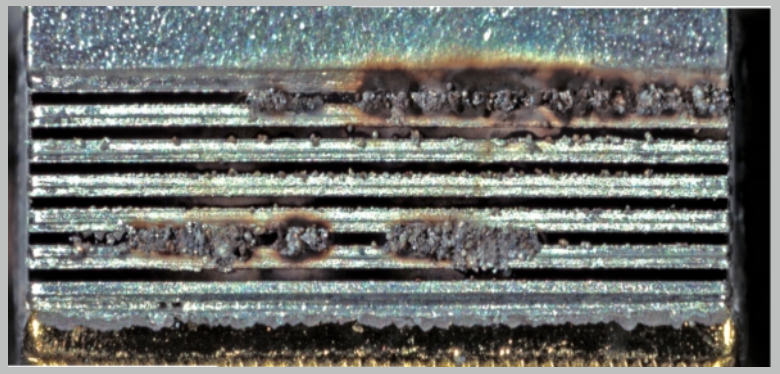
- Experimental Diamond package arrays were lifetime tested along with standard control arrays
- Both standard and diamond packages demonstrated rapid degradation
- Rapid degradation can be partly attributed to deviation from standard assembly processes

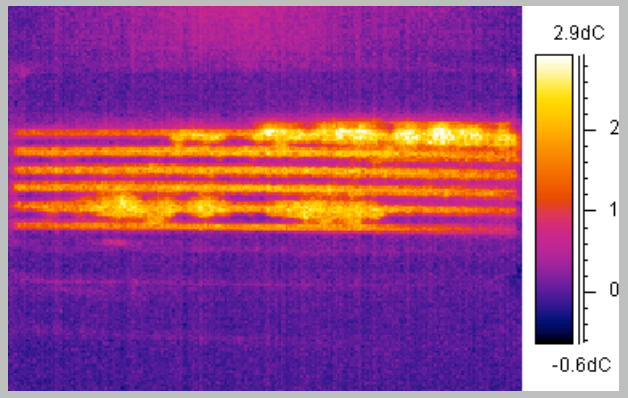


Diamond Laser Diode Array

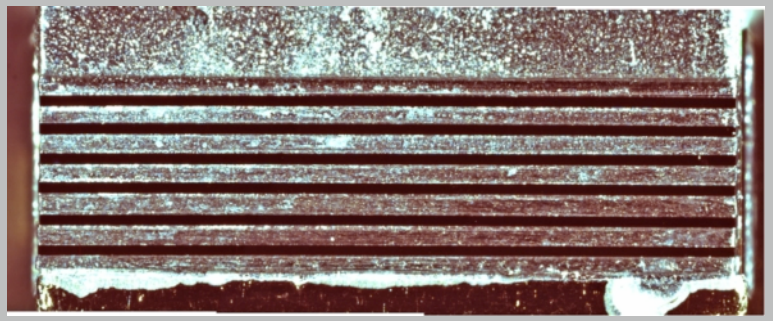
Standard Cu/BeO

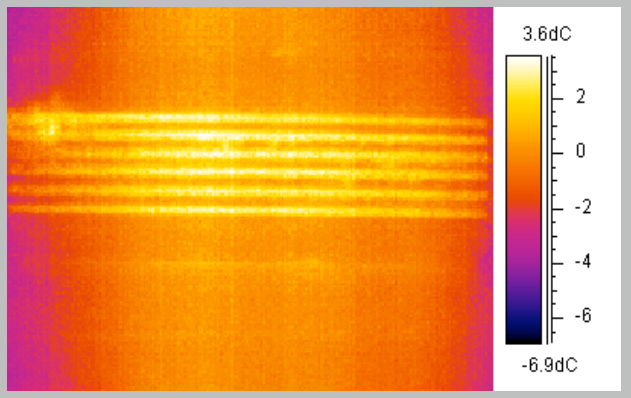






Diamond/Diamond

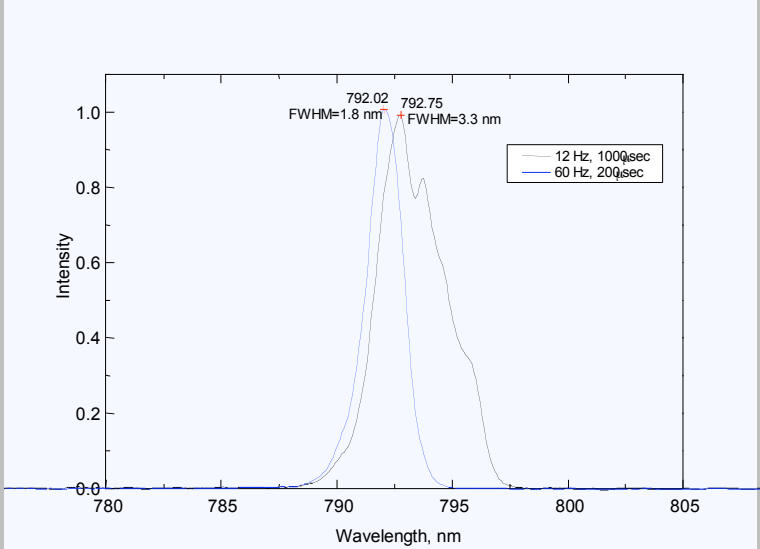




Diamond Laser Diode Array

Spectral response at 200 msec and 1 msec pulse durations

Diamond A-package



Standard G-package